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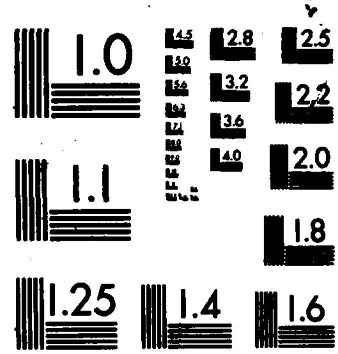

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URBAN EFFECTS ON WINDSPEED IN THE UNITED STATES

Dorathy A. Stewart
Research Directorate
Research, Development,
and Engineering Center

OCTOBER 1986

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

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Urban influences normally weaken strong winds and cause weak winds to increase in speed. Increased urbanization should cause a decrease of standard deviation of speed, and this was observed. Mean speeds in fog at most locations are lower than mean speeds when visibilities are greater. The trends of mean windspeed in fog during a few decades were positive at two American stations where the trends of overall mean speed were negative. The positive trend in fog at a third station was much larger than the positive trend of the overall mean speed. This corroborated previous work with European data.

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IN THE UNITED STATES

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Research Directorate
Research, Development, and Engineering Center
USAMICOM

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I. INTRODUCTION

It has long been known that windspeed and other meteorological variables are not the same in a city as in the surrounding countryside. Most of the relevant literature before 1961 has been reviewed by Landsberg [1] in a definitive book on urban climate. Changnon [2] has edited a monograph which includes the work of several investigators who participated in a major research program in the metropolitan area in and around St. Louis, Missouri. Others have shown that even small cities have an effect on the environment [3,4].

The effect of an urban area on windspeed depends upon the relative magnitudes of opposing influences [5]. Frictional drag retards flow of air. On the other hand, effects of an urban heat island contribute to intensification of winds in a city [6,7]. Reduced stability creates more turbulence which increases flux of momentum from higher altitudes toward the surface. Thermal gradients in an urban environment cause pressure gradients which induce a circulation similar to a sea breeze. Garstang et al. [8] have thoroughly reviewed work on heat islands before 1975, and Oke [9] has presented some more recent observations. Windspeeds are weaker in the city than in the country whenever the effects of the heat island are weaker than the effect of frictional drag. Because the heat island is weakest when regional speeds are strongest, high regional windspeeds are associated with a situation where urban winds are weaker than rural winds [10,11,12]. Windspeeds are higher in the city than in the surrounding countryside when regional speeds are low.

These urban influences provide a good explanation of results of previous work where windspeeds were examined under various meteorological conditions. Windspeed was one of the parameters of interest in an extensive investigation of characteristics of fog [13]. Mean speeds in fog were lower than overall mean speeds at most locations. The magnitude of the difference between the two speeds apparently depended upon the period of record at some stations. Therefore, low visibilities at three German stations during fall and winter were examined in detail [14]. The difference between overall mean speed and mean speed in fog decreased with time at all three stations in both seasons. At Berlin and Frankfurt in winter, the negative trend of the difference was -0.03 m/sec per year.

Evidence from another geographical area was needed to establish that the results of the German study did not represent a unique localized phenomenon. Trends of overall mean windspeed and mean speed in fog at three stations in the United States were examined. Trends of standard deviation were also considered. Standard deviations should decrease as urbanization increases if urban effects weaken strong winds and cause weak winds to increase in speed.

II. ANNUAL TRENDS

Trends at Washington National Airport, LaGuardia, and Chicago (Midway) were examined. Periods were chosen on the basis of availability from the USAF Environmental Technical Applications Center (ETAC) in Asheville, North Carolina. Data were supplied on magnetic tape in the standard TDF 14 code.

Table 1 contains annual mean windspeeds, standard deviations, and the ratio of the standard deviations to means for Washington National Airport. The readily available record on magnetic tape was for July 1941 through November 1981 with March and April 1943 missing. Annual means were computed for 1942 and for the years 1944 through 1980. The speeds and standard deviations in Tables 1 through 6 are in knots as they were on the tape. One knot is equal to 0.5144 m/sec. Annual means were in the range 4.3 to 4.8 m/sec before 1950 and in the range 3.8 to 4.5 m/sec after 1970. There was evidence in the years 1976 through 1980 that the downward trend could be changing. The trend of annual mean speed for the entire period at Washington National Airport was -0.0143 m/sec per year.

The rate of decrease of standard deviation at Washington National Airport was larger. Standard deviations were between 2.5 and 3.0 m/sec during the first few years. All were below 2.3 m/sec during the years 1961 through 1980. The trend of standard deviation at Washington National Airport was -0.0213 m/sec per year.

The ratio of annual standard deviation to annual mean at Washington National Airport also showed a negative trend. Many ratios reached 0.60 during the early years. All were greater than 0.50 until 1958 when the ratio was 0.49. The smallest ratio was 0.47 which occurred in 1977. The trend for the entire period at Washington National Airport was -0.0031 per year.

A comparison of Table 1 with Table 2 shows that winds were significantly stronger at LaGuardia than at Washington National Airport, and standard deviations were slightly larger. Trends of both parameters were considerably larger at LaGuardia than at Washington National Airport. The trend of speed at LaGuardia was -0.0225 m/sec per year. The trend of standard deviation was -0.0368 m/sec per year. The largest ratio of standard deviation to mean speed at LaGuardia was 0.59 in 1953 and 1954, and all were smaller than 0.50 after 1962. The ratios from 1973 to 1980 were in the range 0.41 to 0.44. The trend for the period 1949 through 1980 was -0.0048 per year.

Data in Table 3 are from Chicago (Midway) for the years 1948 through 1978. Mean annual windspeeds were from 4.1 m/sec to 4.8 m/sec during the first decade of the record. The largest annual mean was 5.3 m/sec and it occurred during the second half of the period. The trend of windspeed at Chicago was 0.0144 m/sec per year. This positive trend is consistent with Changnon's finding [15] that windspeeds increased in northern Illinois over the period 1941 through 1980. Annual standard deviations were near 2.3 m/sec throughout the period. The trend was only -0.0009 m/sec per year. The ratios of standard deviation to mean were in the range 0.47 to 0.55 during the decade 1948 to 1957, and in the range 0.45 to 0.51 from 1969 through 1978. The trend of this ratio at Chicago (Midway) was -0.0018 per year.

The present study also considered windspeed in fog. Fog occurs when visibility is less than one kilometer according to the Glossary of Meteorology [16]. One kilometer is not one of the coded distances in the TDF 14 code on our magnetic tapes. Therefore, the analysis of fog considered all visibilities less than or equal to 5/8 mile (1.006 km), which is close enough for practical purposes.

Table 4 contains annual mean windspeeds, standard deviations, and ratios of mean to standard deviation for hours during which fog existed at Washington National Airport. The mean speed in fog for the period of our record was 3.1 m/sec which was considerably smaller than the overall mean of 4.2 m/sec. Annual mean speed and annual mean speed in fog at Washington National Airport have been graphed as a function of time in Figure 1. The trend of speed in fog was positive and the average rate of increase was 0.0353 m/sec per year. Because the overall annual mean speed decreased and the annual mean speed in fog increased, the difference between the two speeds was less at the end of the period than at the beginning. The trend of this difference at Washington National Airport was -0.0496 m/sec per year.

Standard deviations of windspeed in fog and ratios of standard deviation to mean in fog at Washington National Airport fluctuated considerably from year to year. Figures 2 and 3 illustrate this and show the variation of the same quantities for all hours regardless of visibility. During the first half of the period, many of the ratios in fog were greater than unity. During the decade 1971 to 1980, the largest ratio was 0.93 and the smallest was 0.25. The trend of the ratio of standard deviation to mean speed in fog was -0.0092 per year for the entire period. This strong negative trend of the ratio was caused by the positive trend of speed in fog. The trend of standard deviation of windspeed in fog at Washington National Airport was actually the small positive value 0.0021 m/sec per year.

Table 5 lists the annual wind data for hours when fog existed at LaGuardia. The mean speed in fog for the period 1949 to 1980 was 4.67 m/sec which was 0.80 m/sec less than the overall mean speed. The trend of the annual mean speed in fog at LaGuardia was 0.0273 m/sec per year. The trend of the difference between the overall mean speed and the mean speed in fog was -0.0498 m/sec per year. Both this trend and the trend of the difference of the two speeds at Washington National Airport could have been rounded off to -0.050 m/sec per year. It was probably a coincidence that both trends were so close.

Most standard deviations of windspeed in fog at LaGuardia were much less than the mean speeds, especially near the end of the period. The ratios of standard deviation to mean in fog were in the range 0.52 to 1.11 for the years 1949 to 1964, while the range was 0.21 to 0.69 for the years 1965 to 1980. The trend of these ratios for the entire period was -0.0105 per year. This large trend existed because the trend of mean speed in fog was positive and the trend of standard deviations was negative. Standard deviations in fog at LaGuardia had a trend of -0.0308 m/sec per year.

Table 6 contains data for Chicago (Midway) during fog. Mean speed in fog during the years 1948 to 1978 was 3.72 m/sec, which was 0.97 m/sec less than the overall mean speed during the same years. The annual mean speed in fog at Chicago increased at an average rate of 0.0348 m/sec per year from the beginning to the end of the period. This rate of increase was much larger than the rate of increase of the overall mean speed at Chicago. The trend of the difference between the overall mean speed and the mean speed in fog was -0.0204 m/sec per year. These statistics for the three stations are summarized in Table 7.

If a uniform period of record had been used to obtain the trends of the differences for the three stations, the conclusions would have been the same. The 30-year period 1949 to 1978 was readily available for all three stations. The trends of the difference between overall mean speed and mean speed in fog during these three decades were as follows:

LaGuardia = -0.0565 m/sec per year
Washington National Airport = -0.0445 m/sec per year
Chicago = -0.0175 m/sec per year

Table 8 summarizes the data on the trends of standard deviations and their ratio to the means at the three stations. Trends of standard deviation at Chicago during fog have not yet been discussed, and they are not similar to those at the other two stations. The trend of annual standard deviation of windspeed in fog at Chicago was the large positive value of 0.0337 m/sec per year. The trend of the ratio of standard deviation to mean speed in fog was also positive. This latter trend was 0.0030 per year.

A very large research project would be needed to demonstrate conclusively that the proposed mechanism is the major influence on these results. Other influences are possible. Increased release of water vapor into the air by combustion of motor vehicle fuel could permit fog to form more readily. An increase of particulate matter in the atmosphere might allow reduction of visibility below one kilometer with less condensation of water vapor. Finally, an intense heat island under calm conditions could prevent the formation of fog by preventing the temperature of urban air from decreasing to the dew point.

III. MONTHLY VARIATIONS IN WASHINGTON

This section contains graphic illustrations of the monthly mean windspeed, standard deviation of speed, and ratio of standard deviation to mean at Washington National Airport. The discussion of these illustrations includes information about monthly means and computed trends for the period of record.

Figure 4 contains graphs of mean windspeed for the three winter months at Washington National Airport for the winters 1941-42 through 1980-81. Mean windspeeds for the 40 winters increased as winter progressed. They were 4.30, 4.58, and 4.83 m/sec in December, January, and February, respectively. The change of the windspeed trend from one month to the next was much larger. The trend of -0.0040 m/sec per year for December had the smallest magnitudes of any trend for any month of the year. The trend in February had a magnitude more than six times as large and its magnitude was the largest for any month of the year. The trends for January and February were -0.0172 and -0.0258 m/sec per year.

Figure 5 shows the variation of standard deviation over a period of 40 winters. Mean standard deviations increased slightly from the beginning to the end of winter. They were 2.46, 2.54, and 2.62 m/sec in December, January, and February, respectively. Magnitudes of trends also increased between early and late winter. Trends of standard deviation were -0.0146, -0.0165, and -0.0172 m/sec per year for December, January, and February. The trend for December had the smallest magnitude for any month of the year.

The year-to-year change of the dimensionless ratio of the standard deviation to the mean windspeed for winter months at Washington National Airport is shown in Figure 6. The mean ratios for December, January, and February were 0.575, 0.557, and 0.544 with the 0.575 for December being the largest mean for any month of the year. The trend for December was the modest value -0.0028 per year, and the trend for January was even smaller at -0.0015 per year. The trend for February was -0.0007 per year which was the smallest for the year.

Figures 7 and 8 contain the windspeeds and standard deviations of speed for spring months at Washington National Airport. The mean speed for spring was slightly higher than the mean for winter. Speeds were 4.98, 4.81, and 4.25 m/sec for March, April, and May, respectively. The corresponding standard deviations were 2.61, 2.44, and 2.07 m/sec. Trends of speed and standard deviation for March were nearly the same: -0.0205 and -0.0203 m/sec per year. In April, the trend of the speed had a larger magnitude than the trend of standard deviation, and in May the trend of the standard deviation had the larger magnitude. The trends for April were -0.0185 and -0.0153 m/sec per year, and those for May were -0.0213 and -0.0240 m/sec per year. The trend of standard deviation for May was the strongest for any month of the year.

Figure 9 contains ratios of standard deviation to mean speed for the three spring months. They were 0.525, 0.507, and 0.487 for March, April, and May, respectively, and each of these is smaller than the mean for any winter month. The trend of the ratio of standard deviation to mean was only -0.0013 per year in April. The trend in March was -0.0019 per year, and the much larger trend for May was -0.0031 per year.

Graphs for the summer months can be found in Figures 10 through 12. August was the month with the lowest mean windspeed (3.66 m/sec) and the lowest standard deviation of speed (1.78 m/sec). Mean speeds were 4.00 and 3.77 m/sec and standard deviations were 1.93 and 1.80 m/sec for June and July. The trend of speed for July was -0.0150 m/sec per year, which was twice as large as the August trend of -0.0068 m/sec per year. The trend for June was -0.0087 m/sec per year. The trends of standard deviation for the three summer months were -0.0193, -0.0196, and -0.0194 m/sec per year. Mean ratios of standard deviation of speed to mean speed for June, July, and August were 0.483, 0.476, and 0.487. Trends of this ratio were larger in summer than they were in winter and spring. They were -0.0037, -0.0032, and -0.0044 per year in June, July, and August, respectively.

Figures 13 through 15 show the data for fall. Mean speeds in fall increased from 3.76 m/sec in September to 3.98 m/sec in October and 4.22 m/sec in November. The corresponding standard deviations were 1.91 m/sec for September, 2.20 m/sec for October, and 2.39 m/sec for November. Trends of speed for the three months were -0.0092, -0.0096, and -0.0072 m/sec per year. Trends of standard deviation were considerably stronger than trends of speed for all three months of fall. The trend of standard deviation for October was -0.0234 m/sec per year. Trends for September and November were -0.0220 and -0.0204 m/sec per year, respectively. Ratios of standard deviation to mean windspeed increased between the beginning and end of fall, and the magnitudes of the trends of the ratios decreased. Mean ratios were 0.510, 0.554, and 0.569. Trends of the ratios were -0.0048, -0.0044, and -0.0039 per year.

IV. SUMMARY

During an earlier investigation to establish a climatology of windspeed in German fogs, it was discovered that mean speeds varied noticeably from one period of record to another. Subsequent investigation showed that positive trends of windspeed in fog existed at some German sites where trends of overall mean windspeed were negative. It was concluded that urban effects were responsible for this phenomenon since a large metropolitan area weakens strong winds and causes weak winds to increase in speed. Mean windspeeds in fog are lower than overall mean speeds at most sites. Therefore, increased urbanization could easily cause greater speeds in fog while causing lower overall mean speeds during the same period.

Evidence in this report has established that trends of windspeed at three American stations were similar to trends found in Europe. Trends of the difference between overall annual mean speed and annual mean speed in fog were -0.050 m/sec per year at both Washington National Airport and LaGuardia. The trends of overall mean speed were negative and the trends of speed in fog were positive at both stations. Both trends were positive at Chicago, but the trend of the mean speed in fog was much larger. The trend of the difference at Chicago was -0.020 m/sec per year. Trends of annual standard deviation and ratio of standard deviation to mean were negative at all three stations. Trends of these variables in fog could be either positive or negative.

Trends for individual months at Washington National Airport were examined. Trends of mean speed were negative in all months, but magnitudes were less than 0.0100 m/sec per year in June and in August through December. The strongest trend of speed was in February when it was -0.0258 m/sec per year. All trends of standard deviation were negative. Those for every month were in the range -0.0146 to -0.0240 m/sec per year. All monthly trends of the ratio of the standard deviation to mean were negative with strongest trends in late summer and in fall. The trend in September was -0.0048 per year, while both August and October had trends of -0.0044 per year. The weakest trend of the ratio was in February when it was only -0.0007 per year.

The final conclusion is that a phenomenon which has appeared in both Europe and the United States should not be ignored. Trends of meteorological parameters have occurred in metropolitan areas in the last few decades. It cannot be assumed that the trend of any variable is uniform and uncorrelated with other atmospheric variables.

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TABLE 1. Annual Mean Windspeed, Standard Deviation of Speed, and Ratio of Standard Deviation to Mean at Washington National Airport

Year	Mean (knots)*	σ (Knots)*	σ/Mean
1942	9.1	5.5	.60
1943	—	—	—
1944	9.3	5.1	.55
1945	8.6	5.5	.64
1946	9.1	5.8	.64
1947	8.6	5.2	.60
1948	8.6	5.2	.60
1949	8.4	4.8	.57
1950	9.2	5.1	.55
1951	8.4	5.1	.61
1952	8.4	5.2	.62
1953	8.0	4.8	.60
1954	8.7	4.7	.54
1955	8.9	4.7	.53
1956	8.5	4.8	.56
1957	8.6	4.7	.55
1958	8.6	4.2	.49
1959	8.1	4.6	.57
1960	8.9	4.8	.54
1961	7.3	4.1	.56
1962	7.0	3.9	.56
1963	7.4	4.2	.57
1964	8.1	4.2	.52
1965	7.7	4.2	.55
1966	7.9	3.9	.49
1967	7.7	4.1	.53
1968	7.7	4.1	.53
1969	7.8	4.1	.53
1970	7.4	3.8	.51
1971	8.4	4.4	.52
1972	7.7	3.9	.51
1973	7.3	3.8	.52
1974	7.5	3.9	.52
1975	7.3	4.1	.56
1976	8.4	4.1	.49
1977	8.8	4.1	.47
1978	8.5	4.3	.51
1979	8.4	4.1	.49
1980	8.5	4.3	.51

* 1 knot = 0.5144 m/sec

TABLE 2. Annual Mean Windspeed, Standard Deviation of Speed, and Ratio of Standard Deviation to Mean at LaGuardia

Year	Mean (Knots)*	σ (Knots)*	$\frac{\sigma}{\text{Mean}}$
1949	10.6	5.5	.52
1950	10.8	6.0	.56
1951	11.0	6.0	.55
1952	12.0	6.3	.52
1953	10.7	6.3	.59
1954	10.7	6.3	.59
1955	11.4	6.3	.55
1956	11.7	5.4	.46
1957	11.3	5.0	.44
1958	11.2	5.2	.46
1959	12.2	5.5	.45
1960	11.6	6.0	.52
1961	11.6	6.0	.52
1962	10.7	5.2	.49
1963	10.4	4.5	.43
1964	10.3	4.3	.42
1965	9.6	3.7	.39
1966	9.7	4.2	.43
1967	10.2	4.3	.42
1968	10.1	4.4	.44
1969	10.1	4.3	.43
1970	10.4	4.0	.38
1971	10.4	4.6	.44
1972	10.1	4.5	.45
1973	10.2	4.2	.41
1974	9.4	4.0	.43
1975	9.2	4.0	.43
1976	10.8	4.4	.41
1977	9.7	4.2	.43
1978	10.2	4.3	.42
1979	10.1	4.4	.44
1980	11.6	4.7	.41

* 1 Knot = 0.5144 m/sec

TABLE 3. Annual Mean Windspeed, Standard Deviation of Speed, and Ratio of Standard Deviation to Mean at Chicago (Midway)

Year	Mean (Knots)*	σ (Knots)*	σ / Mean
1948	8.2	4.5	.55
1949	8.3	4.3	.52
1950	8.7	4.7	.54
1951	8.1	4.3	.53
1952	8.4	4.2	.50
1953	9.2	4.7	.51
1954	9.3	4.4	.47
1955	9.2	4.4	.48
1956	8.1	4.1	.51
1957	8.0	4.4	.55
1958	8.8	4.1	.47
1959	9.7	4.6	.47
1960	10.0	4.9	.49
1961	9.6	4.7	.49
1962	9.3	4.7	.51
1963	9.1	4.6	.51
1964	9.4	4.7	.50
1965	10.0	4.6	.46
1966	9.3	4.6	.49
1967	9.8	4.5	.46
1968	10.3	4.7	.46
1969	9.2	4.4	.48
1970	9.6	4.5	.47
1971	9.6	4.7	.49
1972	9.3	4.5	.48
1973	8.3	4.2	.51
1974	8.6	4.2	.49
1975	8.8	4.3	.49
1976	9.7	4.5	.46
1977	9.6	4.3	.45
1978	8.8	4.2	.48

*1 Knot = 0.5144 m/sec

TABLE 4. Annual Mean Windspeed in Fog, Standard Deviation of Speed in Fog, and Ratio of Standard Deviation to Mean at Washington National Airport

Year	Mean (Knots)*	σ (Knots)*	σ / Mean
1942	4.5	4.2	.93
1943	—	—	—
1944	4.5	3.2	.71
1945	4.8	4.9	1.02
1946	3.7	4.1	1.11
1947	6.0	5.5	.92
1948	6.5	6.6	1.02
1949	5.1	3.6	.71
1950	3.5	4.4	1.26
1951	5.3	3.5	.66
1952	4.0	3.5	.88
1953	4.9	5.3	1.08
1954	7.5	4.8	.64
1955	6.3	5.5	.87
1956	5.4	3.6	.67
1957	4.9	3.8	.78
1958	7.7	4.4	.57
1959	3.6	4.2	1.17
1960	9.0	6.8	.76
1961	6.3	4.5	.71
1962	4.9	2.9	.59
1963	4.3	2.5	.58
1964	6.5	5.6	.86
1965	5.2	4.5	.87
1966	9.4	5.6	.60
1967	6.6	4.3	.65
1968	9.0	7.2	.80
1969	6.2	5.3	.85
1970	5.8	4.5	.78
1971	6.4	4.5	.70
1972	6.5	5.3	.82
1973	5.6	4.2	.75
1974	5.6	3.4	.61
1975	5.0	3.3	.66
1976	7.5	7.0	.93
1977	5.2	1.3	.25
1978	8.4	6.7	.80
1979	7.7	4.7	.61
1980	8.6	3.6	.42

* 1 Knot = 0.5144 m/sec

TABLE 5. Annual Mean Windspeed in Fog, Standard Deviation of Speed in Fog, and Ratio of Standard Deviation to Mean at LaGuardia

Year	Mean (Knots)*	σ (Knots)*	$\frac{\sigma}{\text{Mean}}$
1949	8.1	6.2	.77
1950	7.5	3.9	.52
1951	5.4	3.0	.56
1952	8.1	6.8	.84
1953	5.3	5.9	1.11
1954	6.9	4.5	.65
1955	7.4	4.8	.65
1956	9.6	8.9	.93
1957	8.4	5.4	.64
1958	11.4	8.6	.75
1959	10.8	5.6	.52
1960	14.6	8.9	.61
1961	12.1	11.4	.94
1962	8.0	4.9	.61
1963	7.7	4.1	.53
1964	11.1	8.5	.77
1965	8.6	3.8	.44
1966	11.2	6.1	.54
1967	10.6	6.4	.60
1968	8.2	3.0	.37
1969	15.8	7.8	.49
1970	8.1	3.4	.42
1971	6.8	3.7	.54
1972	6.9	4.6	.67
1973	6.2	3.7	.60
1974	6.2	4.3	.69
1975	7.2	3.0	.42
1976	10.7	6.2	.58
1977	6.6	3.5	.53
1978	15.1	8.6	.57
1979	9.5	4.4	.46
1980	10.2	2.1	.21

* 1 Knot = 0.5144 m/sec

TABLE 6. Annual Mean Windspeed in Fog, Standard Deviation of Speed in Fog, and Ratio of Standard Deviation to Mean at Chicago (Midway)

Year	Mean (Knots)*	σ (Knots)*	$\frac{\sigma}{\text{Mean}}$
1948	4.9	3.9	.80
1949	4.8	2.0	.42
1950	6.4	4.5	.70
1951	5.6	4.0	.71
1952	6.0	4.1	.68
1953	6.8	3.8	.56
1954	7.7	4.0	.52
1955	9.0	7.7	.86
1956	4.9	3.5	.71
1957	5.7	3.6	.63
1958	5.3	3.4	.64
1959	7.3	4.6	.63
1960	8.7	5.2	.60
1961	8.7	6.0	.69
1962	6.9	3.9	.57
1963	7.9	5.1	.65
1964	9.6	5.6	.58
1965	7.9	5.3	.67
1966	8.0	3.8	.47
1967	10.6	8.1	.76
1968	8.1	3.9	.48
1969	5.8	4.7	.81
1970	9.5	8.4	.88
1971	7.5	5.9	.79
1972	8.6	5.0	.58
1973	4.9	2.8	.57
1974	6.4	4.3	.67
1975	6.4	6.0	.94
1976	6.3	5.2	.83
1977	7.2	4.3	.60
1978	10.6	7.7	.73

* 1 Knot = 0.5144 m/sec

TABLE 7. Trends of Annual Mean Windspeed, Mean Speed in Fog, and Difference of the Two Means at Three Stations in the United States (Units are Meters Per Second Per Year)

Station	Trend of Windspeed	Trend of Windspeed in Fog	Trend of Difference
Wash. National	-0.0143	+0.0353	-0.0496
LaGuardia	-0.0225	+0.0273	-0.0498
Chicago Midway	+0.0144	+0.0348	-0.0204

TABLE 8. Trends of Annual Standard Deviations of Windspeed and Ratios of Standard Deviations to Means For all Hours and For Fog at Three Stations in the United States

Trend Variable with Units	Station		
	Washington National	LaGuardia	Chicago Midway
σ (m sec^{-1} yr^{-1})	-0.0213	-0.0368	-0.0009
σ in fog (m sec^{-1} yr^{-1})	+0.0021	-0.0308	+0.0337
σ/speed (yr^{-1})	-0.0031	-0.0048	-0.0018
σ/speed in fog (yr^{-1})	-0.0092	-0.0105	+0.0030

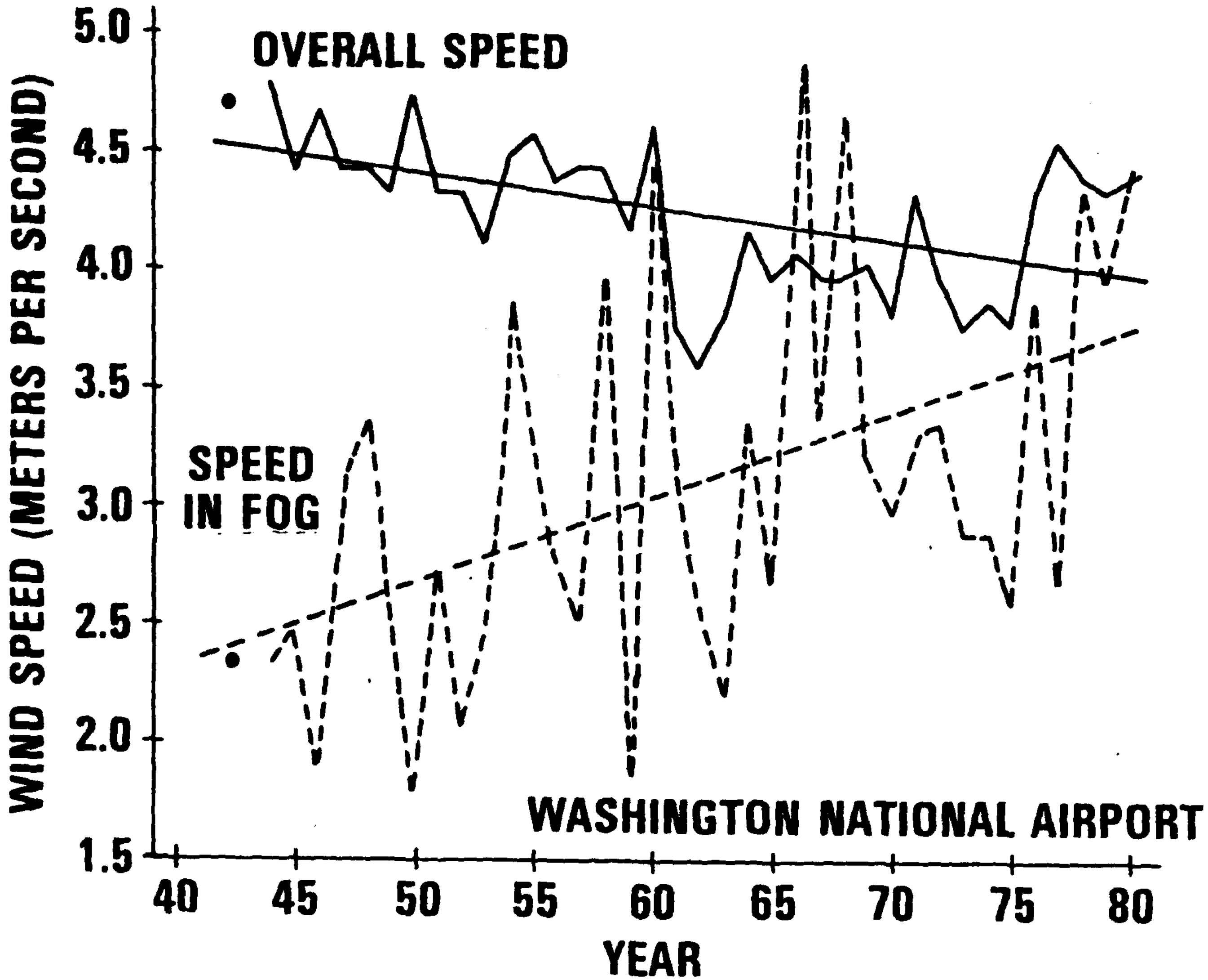

Figure 1. Annual mean windspeed and mean speed in fog at Washington National Airport from 1942 to 1980.

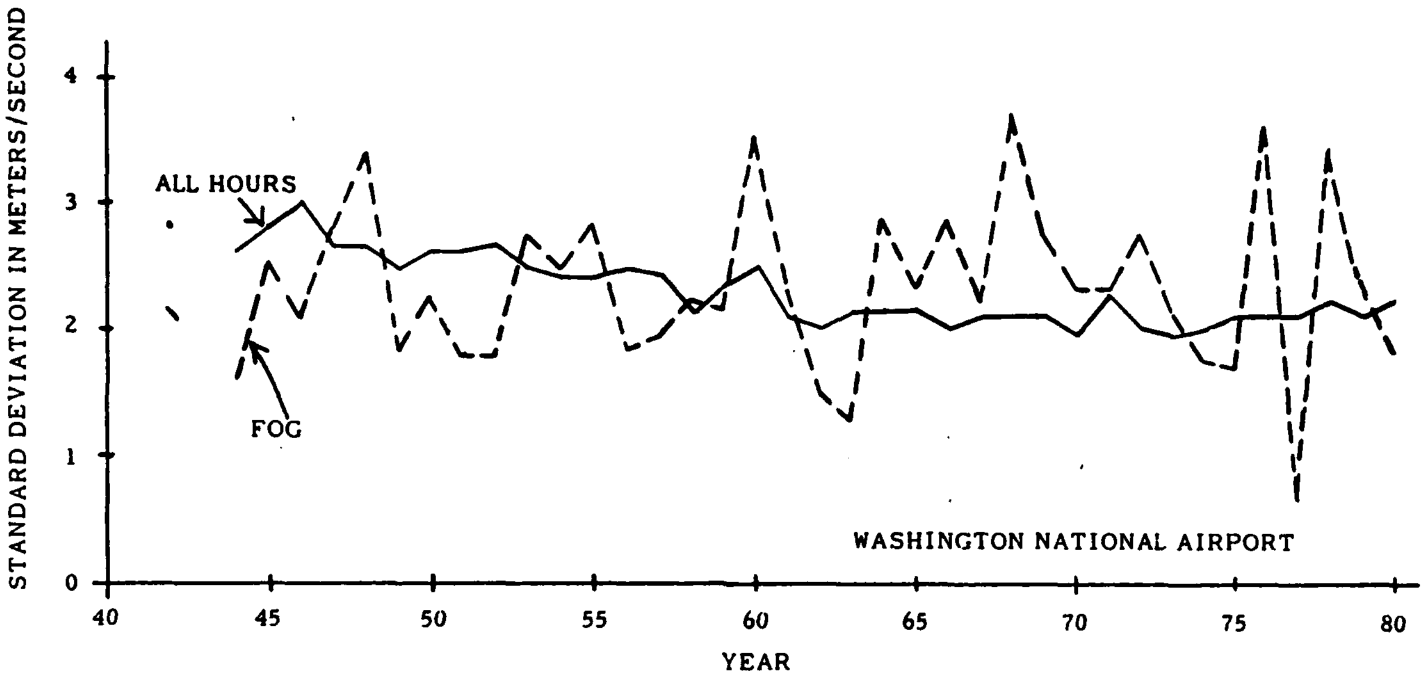

Figure 2. Annual standard deviations of all windspeeds and speeds in fog at Washington National Airport from 1942 to 1980.

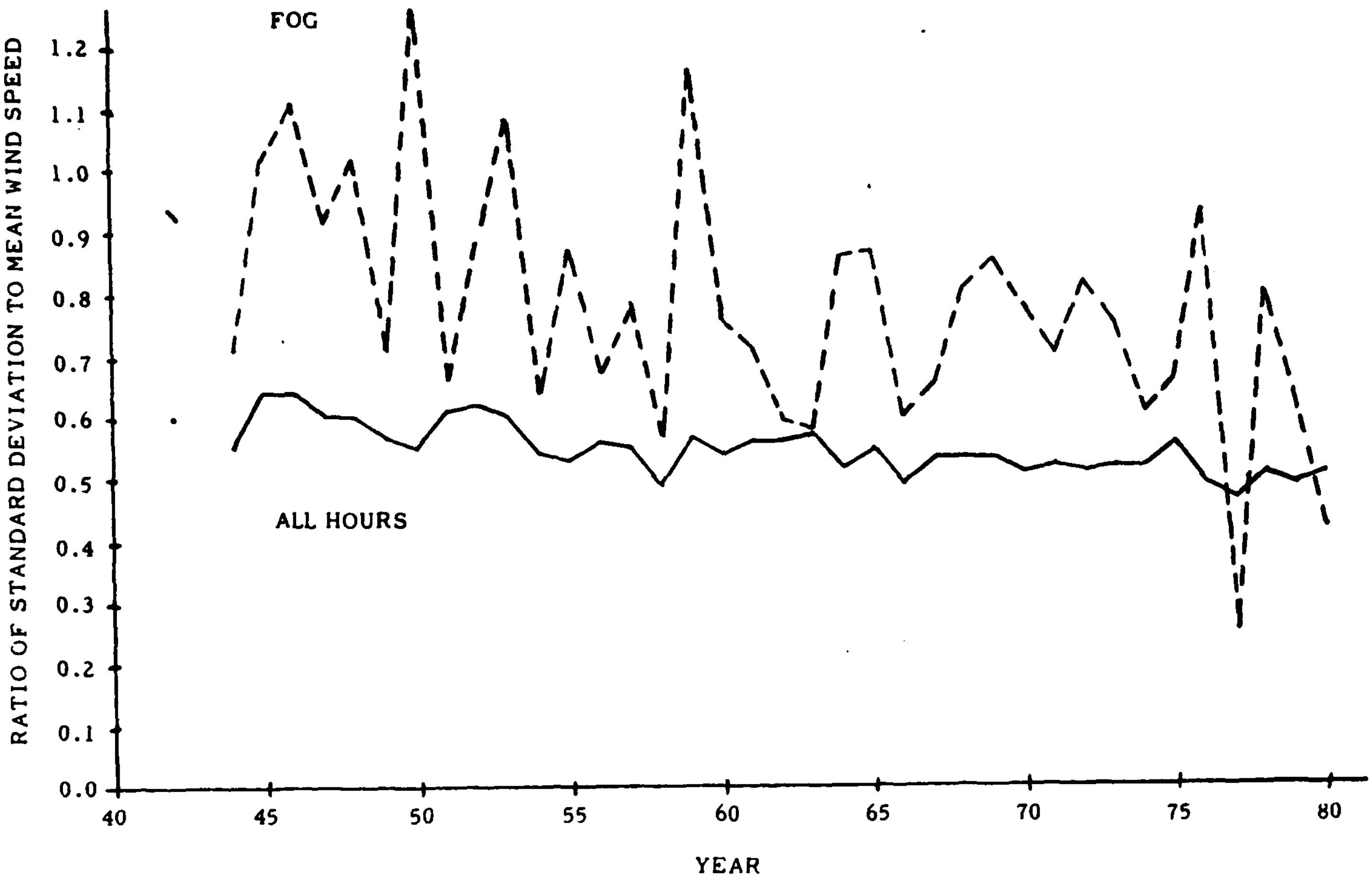

Figure 3. Ratios of standard deviations to annual mean windspeeds for all hours and for hours with fog at Washington National Airport from 1942 to 1980.

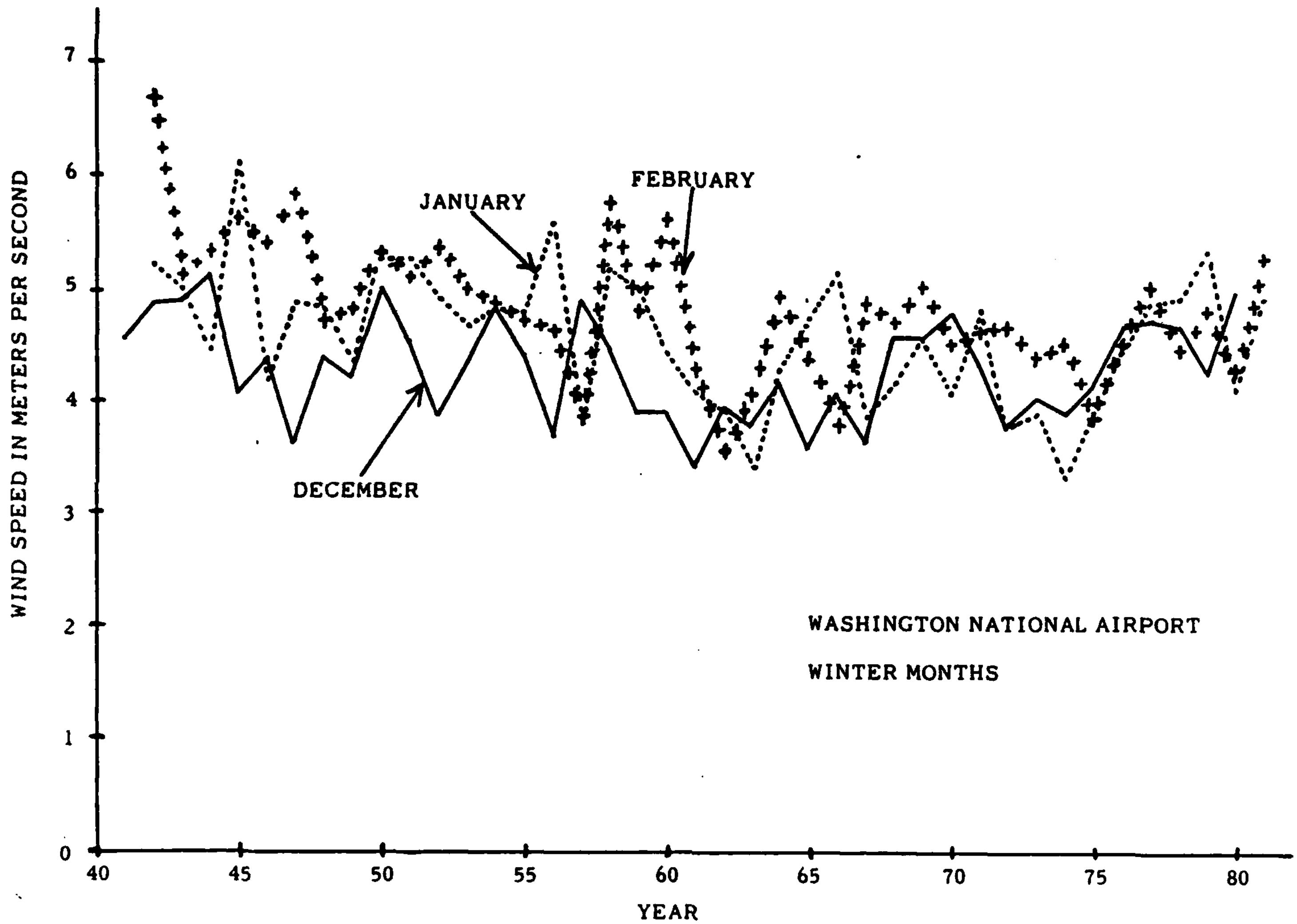

Figure 4. Mean windspeeds for each of the three winter months at Washington National Airport.

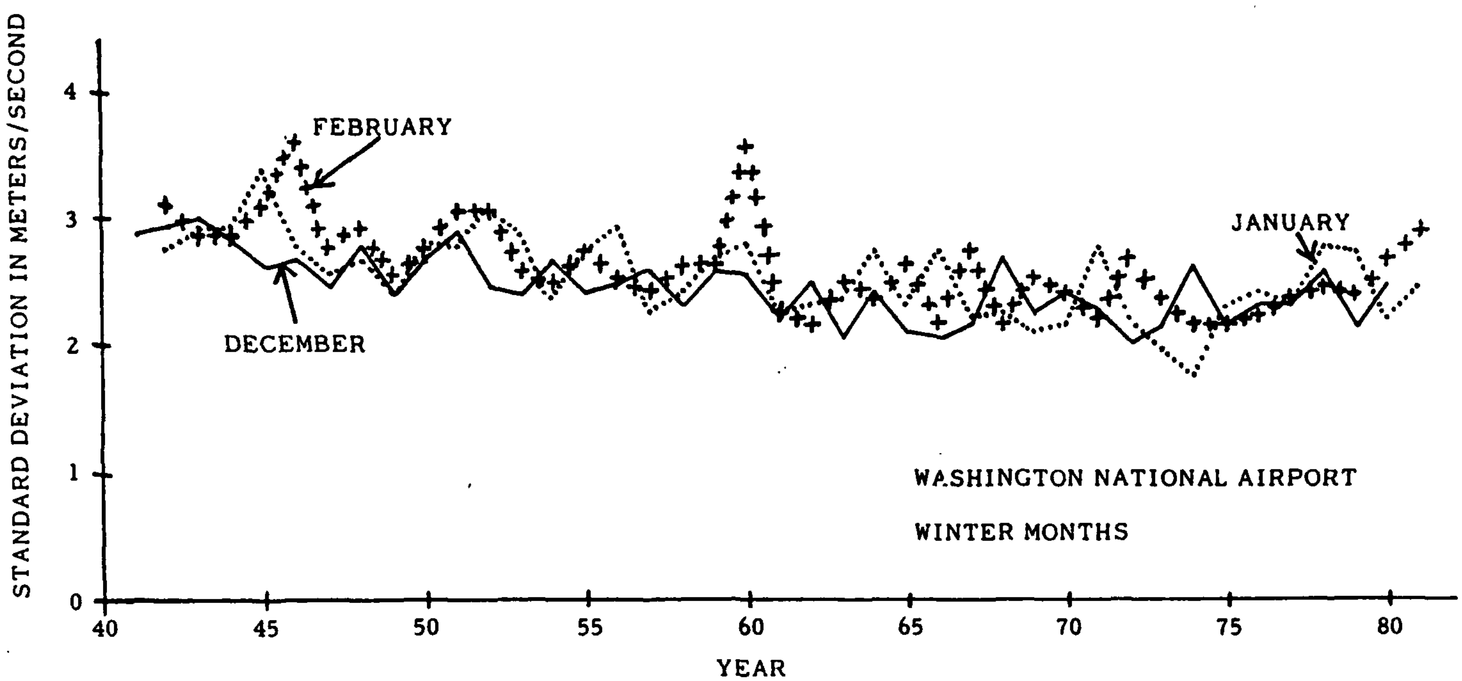

Figure 5. Standard deviations of windspeed for each of the three winter months at Washington National Airport.

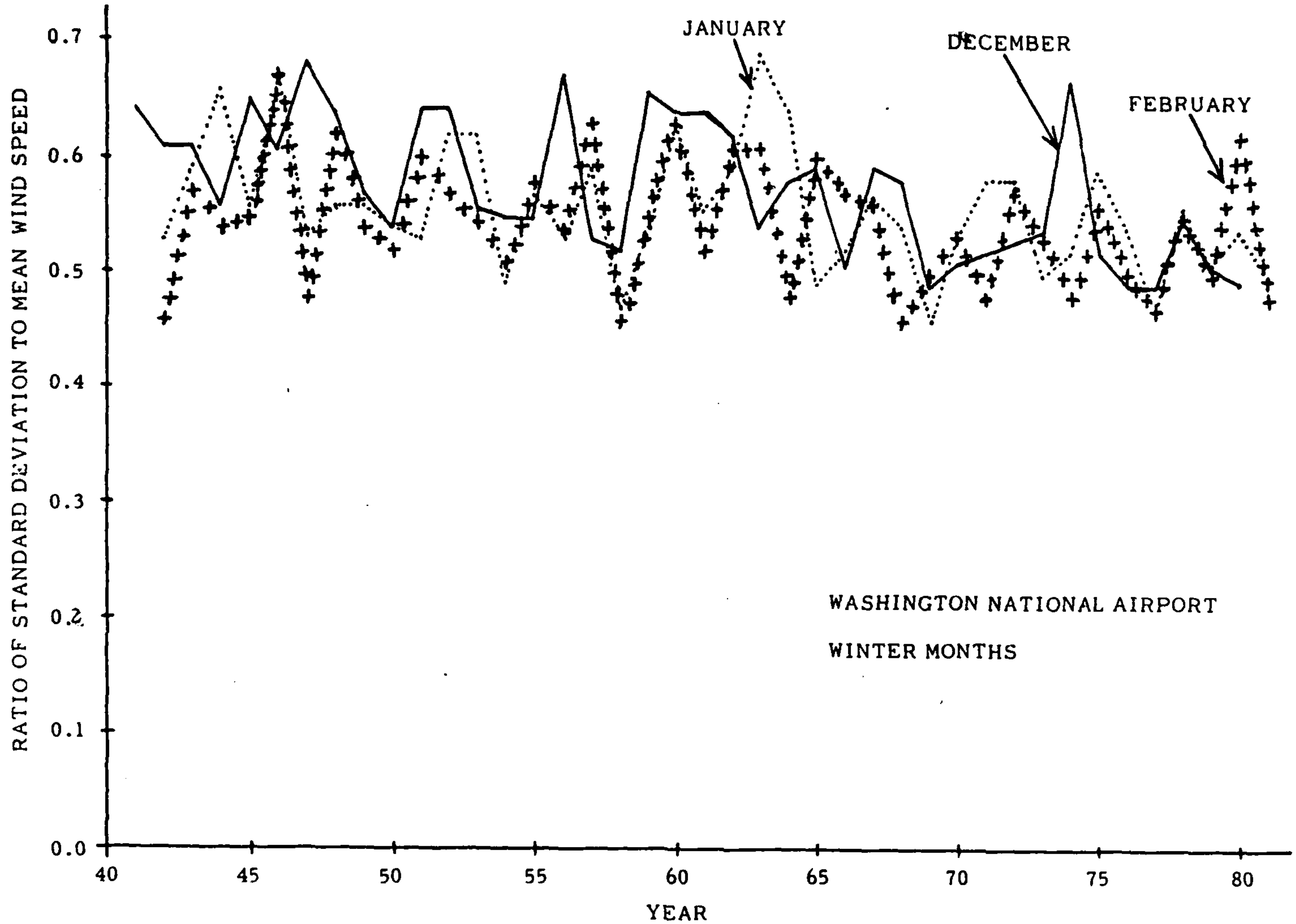

Figure 6. Ratios of standard deviations to mean windspeeds for each of the three winter months at Washington National Airport.

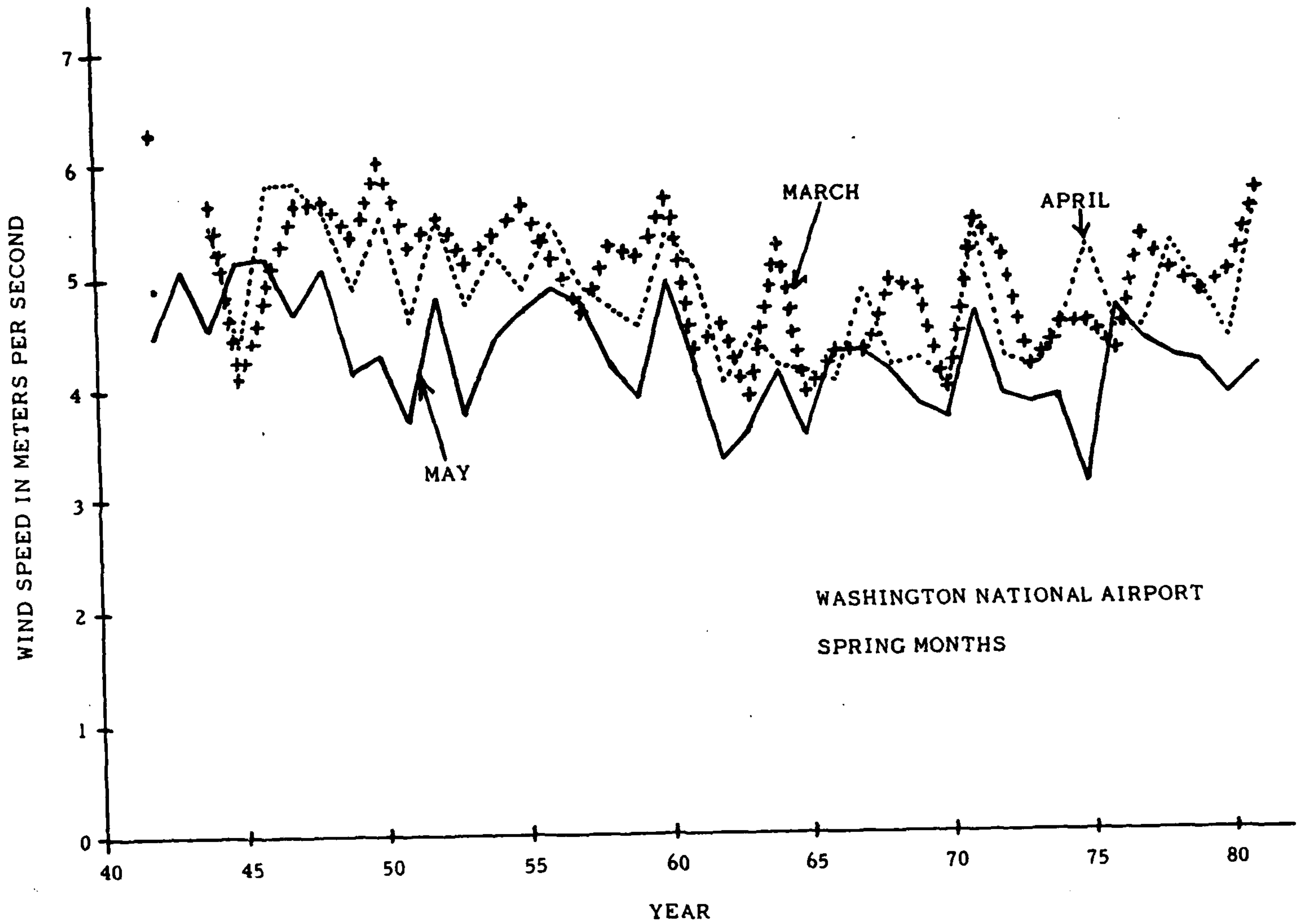

Figure 7. Mean windspeeds for each of the three spring months at Washington National Airport.

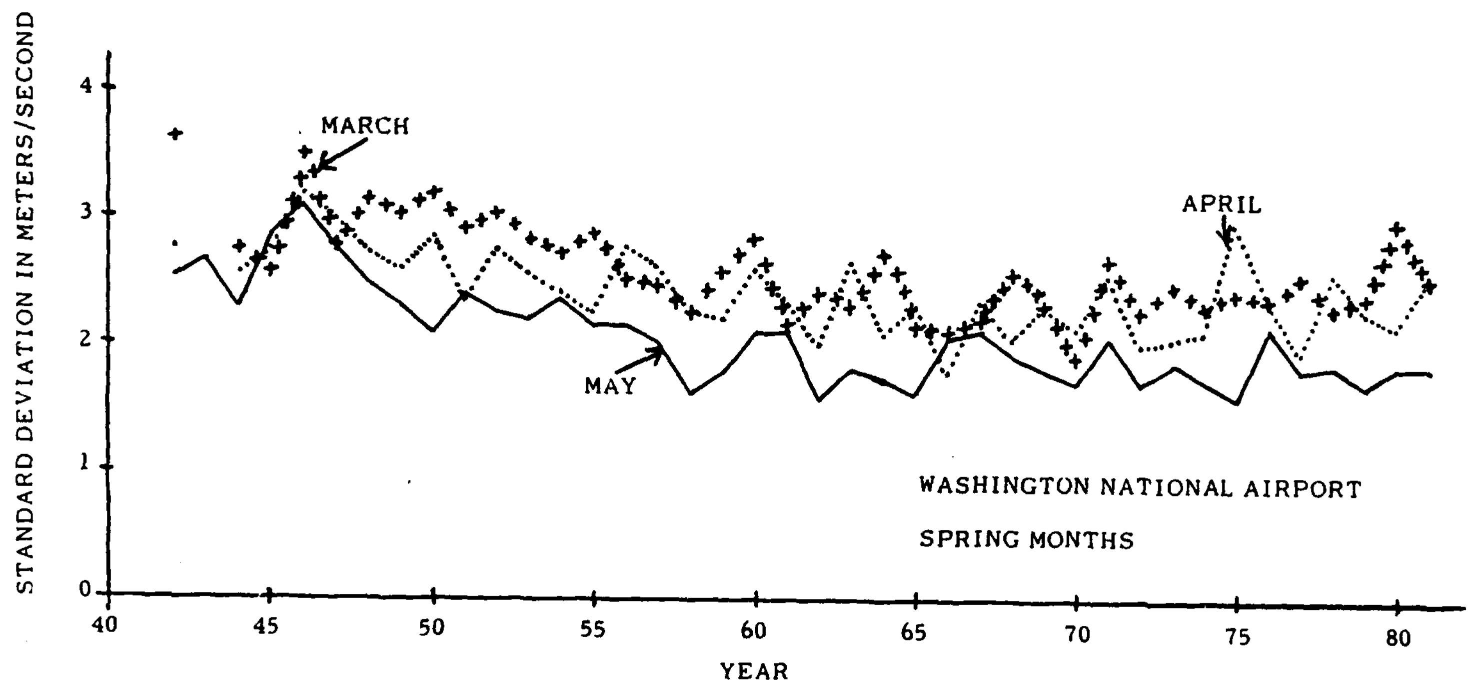

Figure 8. Standard deviations of windspeed for each of the three spring months at Washington National Airport.

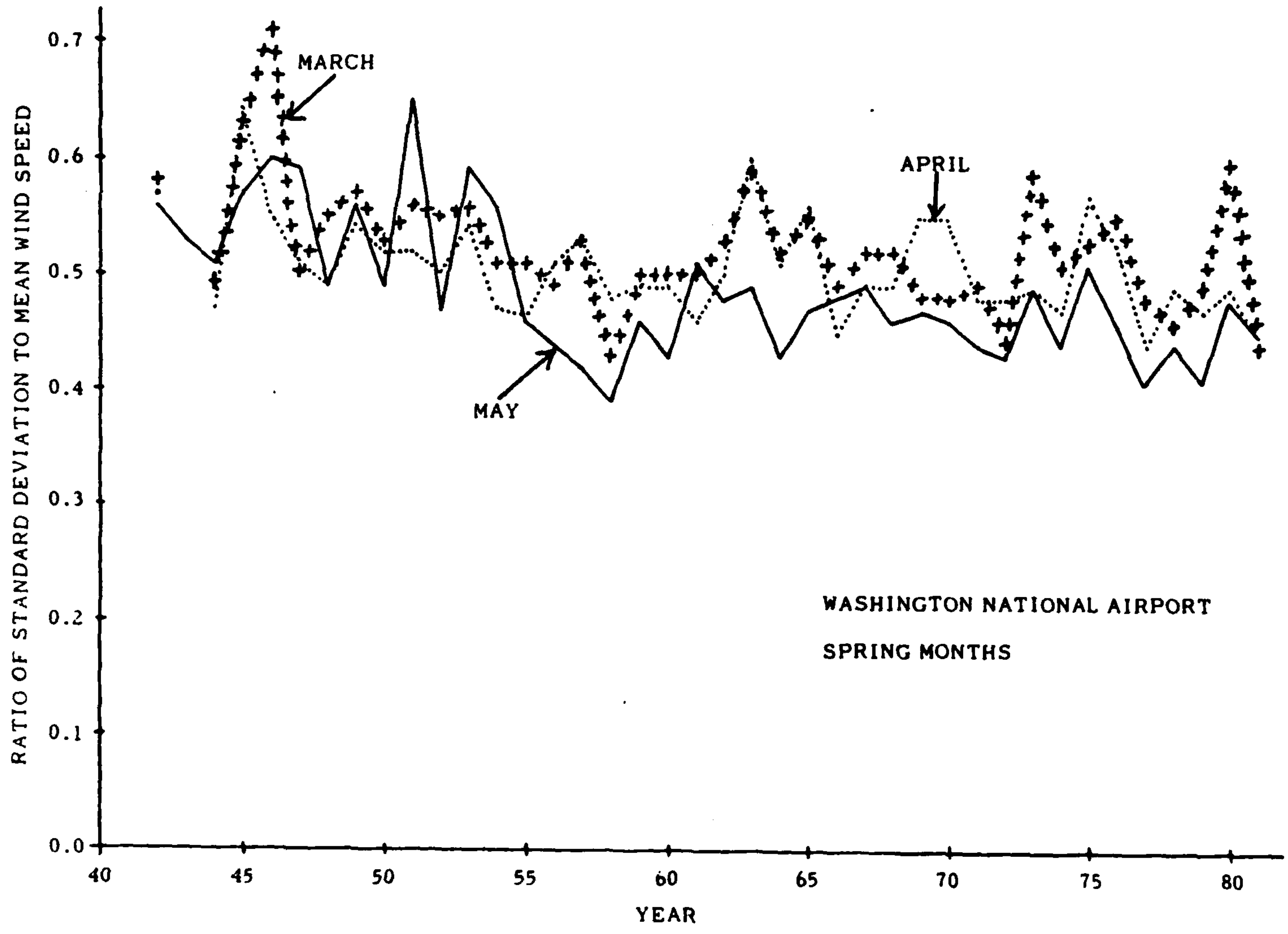

Figure 9. Ratios of standard deviations to mean windspeeds for each of the three spring months at Washington National Airport.

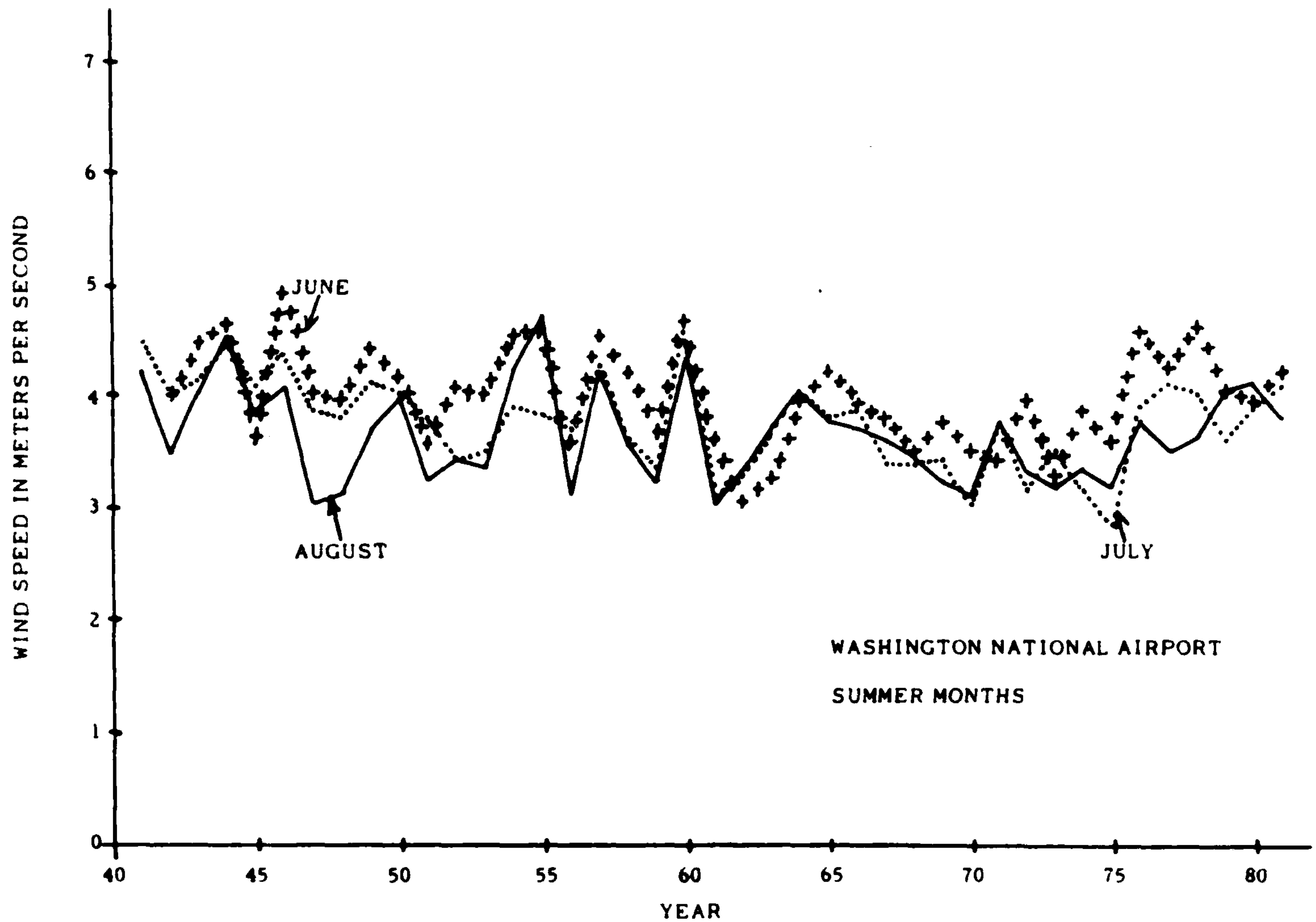

Figure 10. Mean windspeeds for each of the three summer months at Washington National Airport.

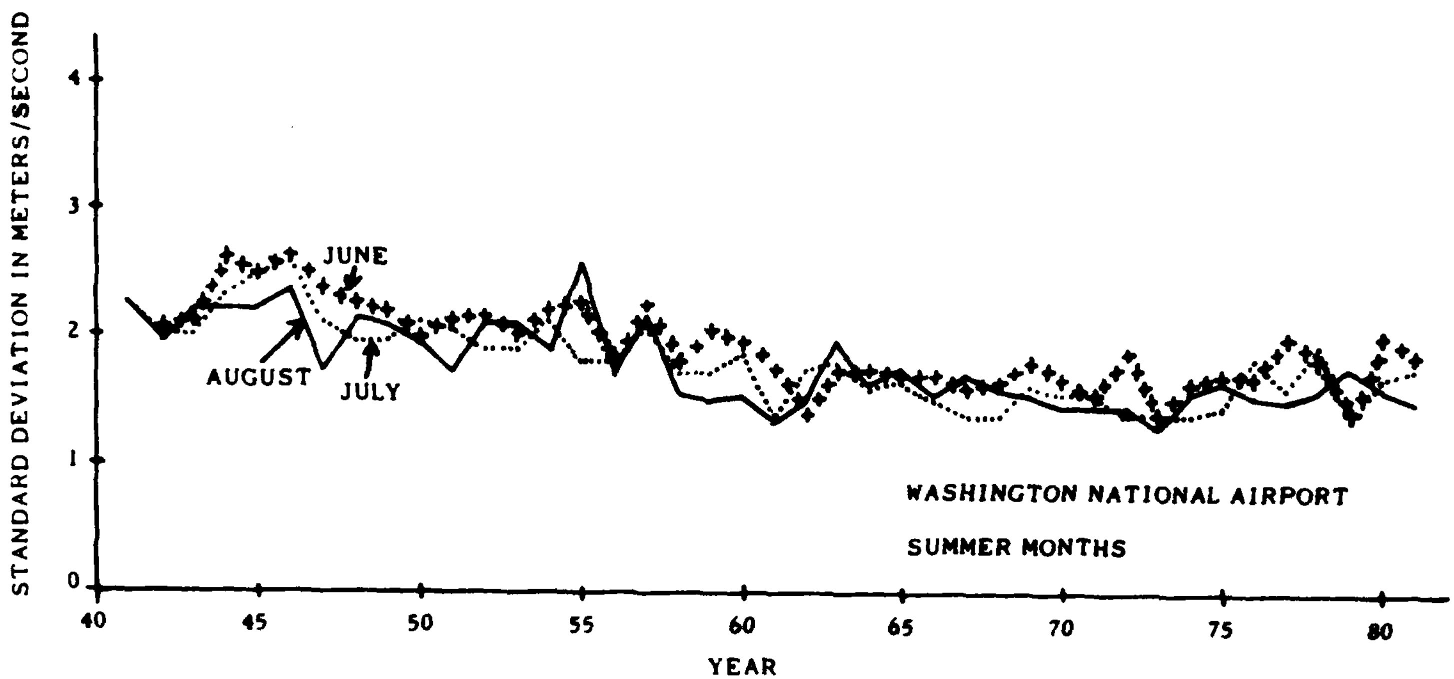

Figure 11. Standard deviations of windspeed for each of the three summer months at Washington National Airport.

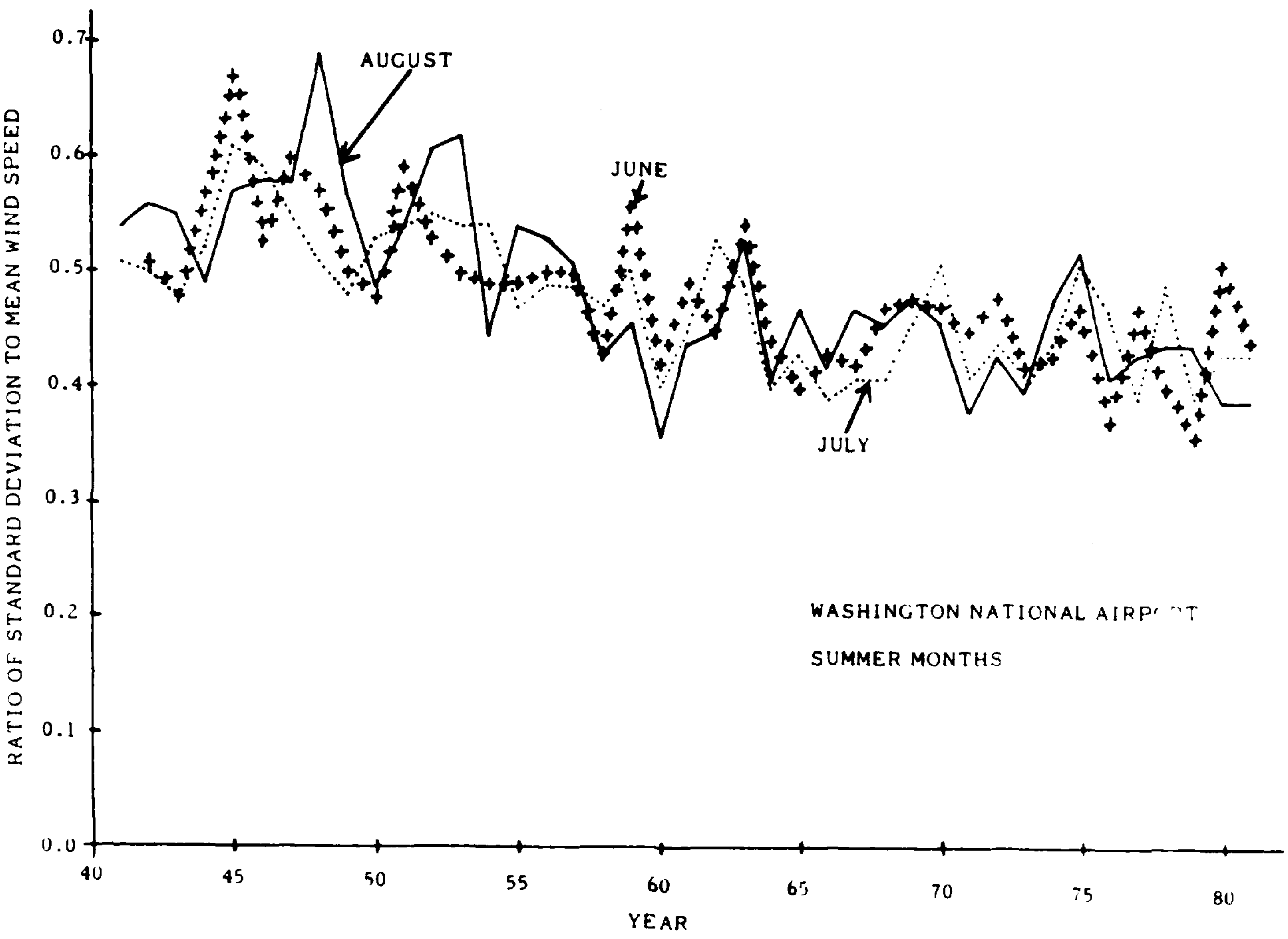

Figure 12. Ratios of standard deviations to mean windspeeds for each of the three summer months at Washington National Airport.

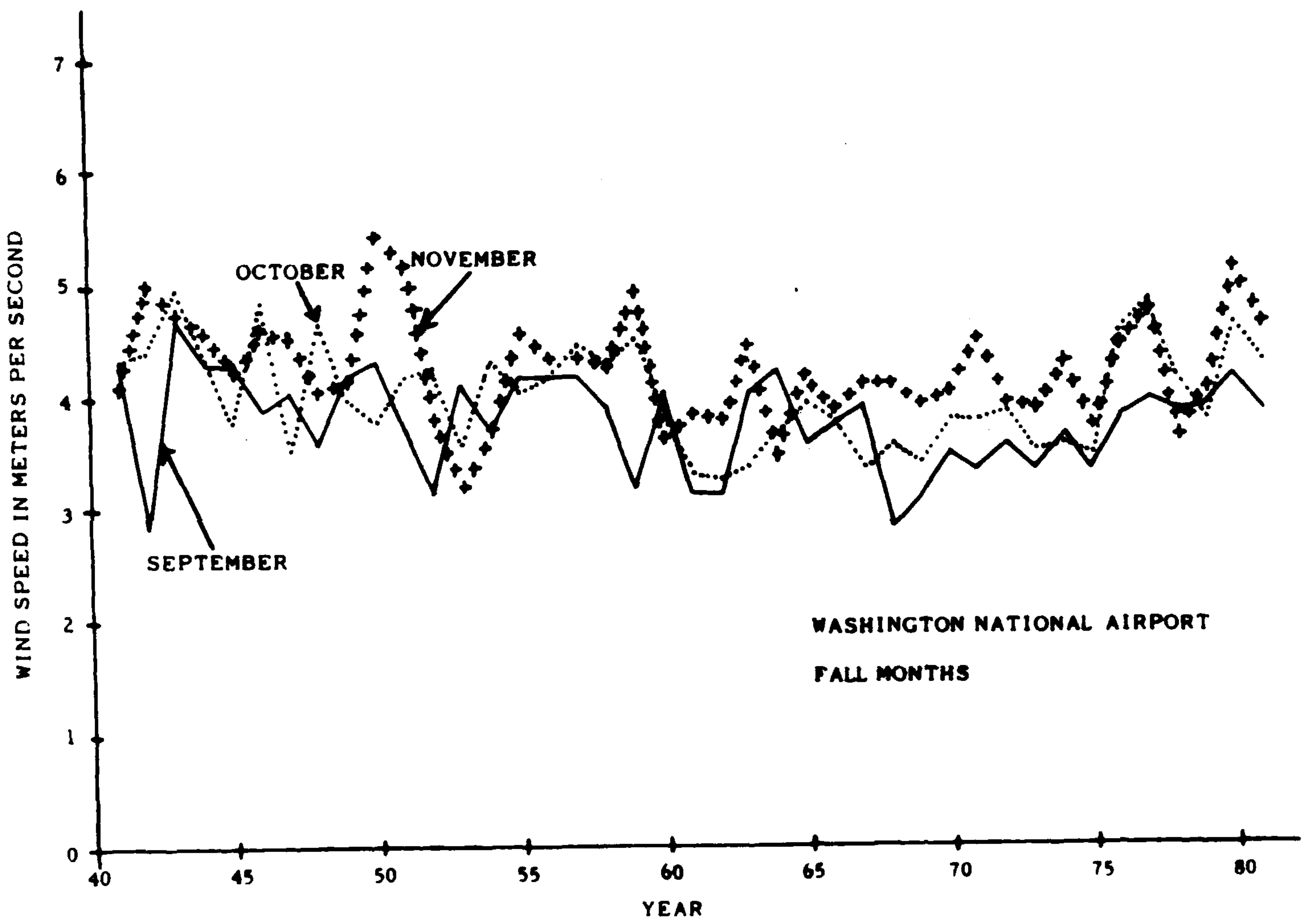

Figure 13. Mean windspeeds for each of the three fall months at Washington National Airport.

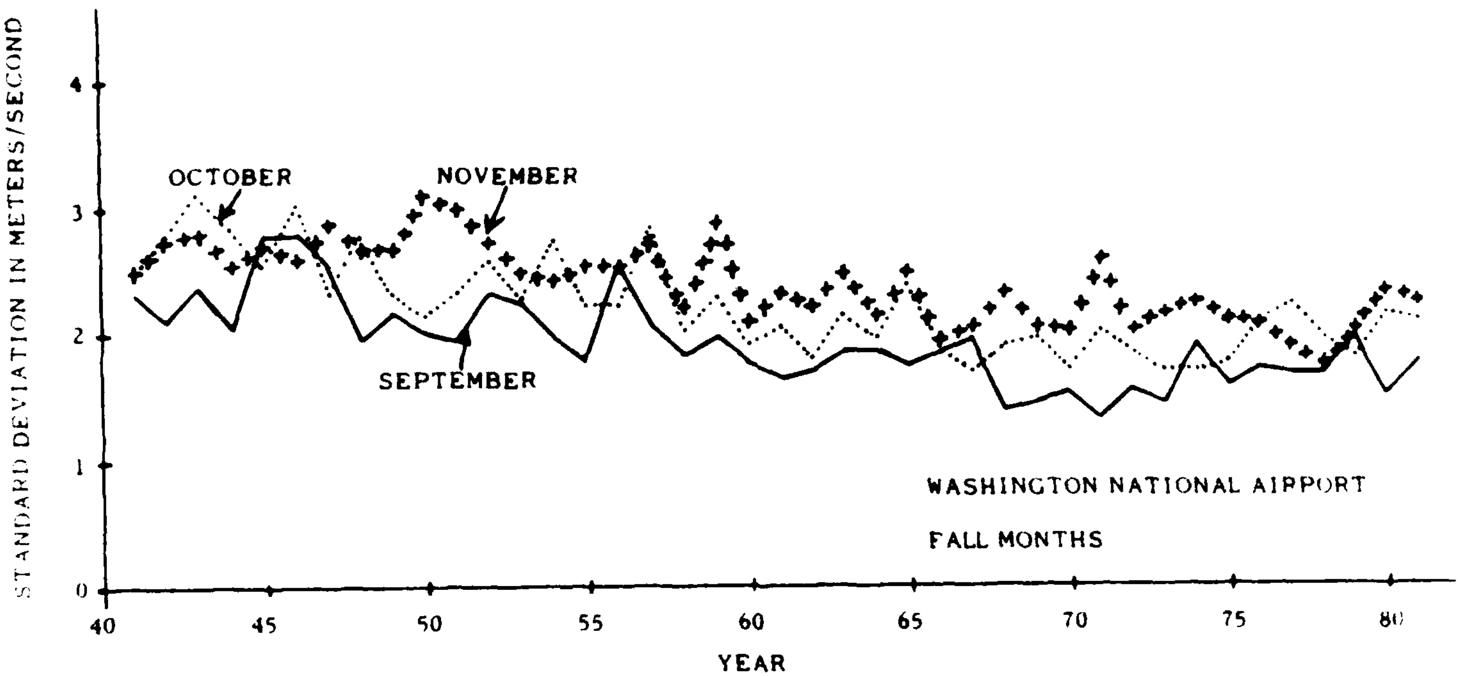

Figure 14. Standard deviations of windspeed for each of the three fall months at Washington National Airport.

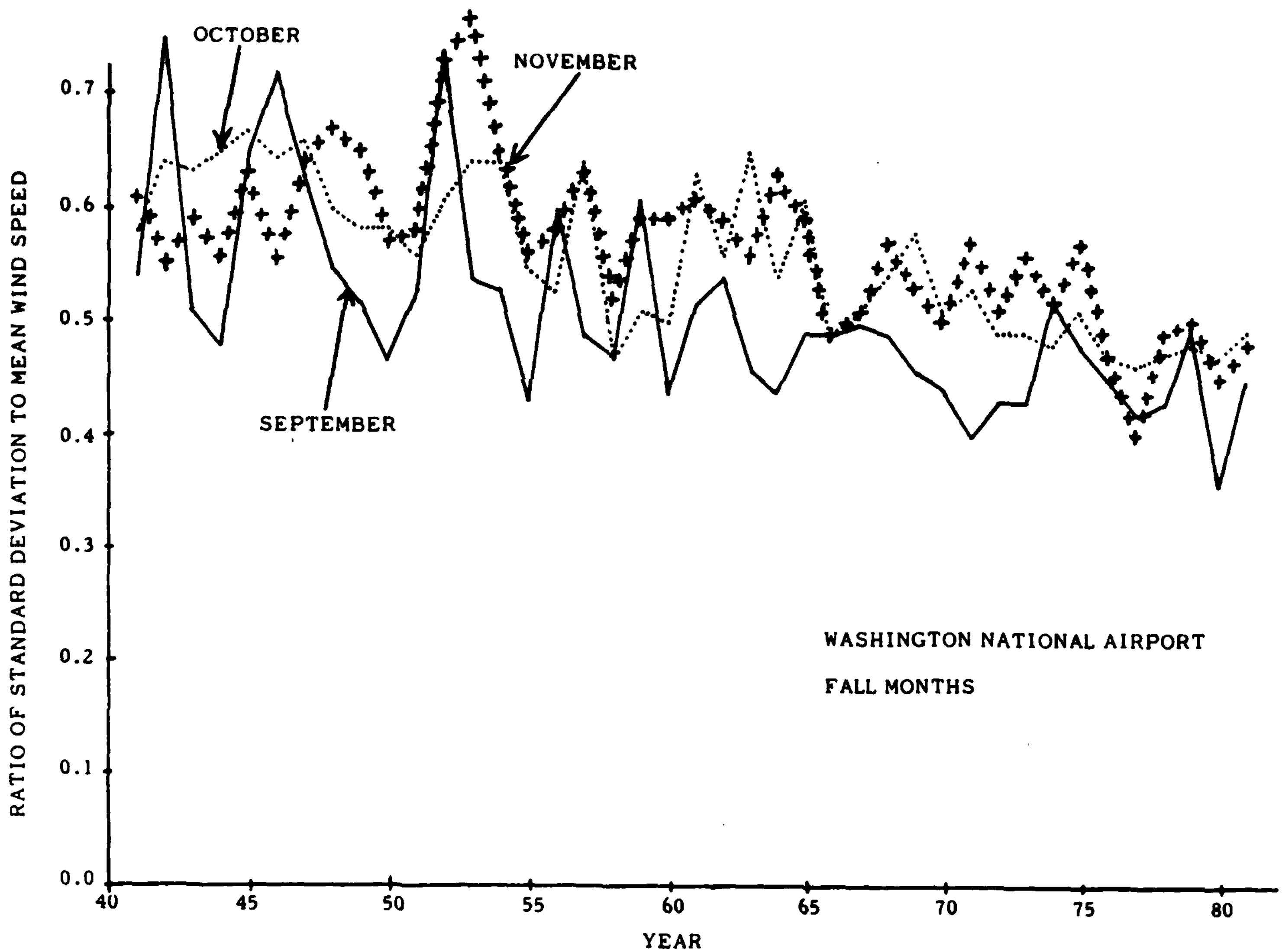

Figure 15. Ratios of standard deviations to mean windspeeds for each of the three fall months at Washington National Airport.

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